BLAINE T. REELY, PHD, PE
CIVIL ENGINEER - HYDROLOGIST

Tentative Determination of Maximum Annual Yield of Groundwater From Arbuckle - Simpson Groundwater Basin Hearing
May 15-16, 2012

EDUCATIONAL SUMMARY

High School - Bullhead City, Arizona (1974)
BSc - University of Arizona (Geological Engineering) (1980)
MSc - University of Arizona (Civil Engineering) Geotechnical / Water Resources (1985)
PhD - Oklahoma State University (Civil Engineering) Water Resources (1992)

MSc Thesis: Strength & Durability of Soil Cement for Flood Control Channel Bank Stabilization
PhD Dissertation: A Linked Simulation - Optimization Groundwater Management Model - Cimarron River Terrace & Alluvial Aquifer
PROFESSIONAL EXPERIENCE

City of Enid
Enid, Oklahoma – Municipal Public Works

Envirotech Services
OK/AZ/CA – Civil Engineering & Hydrology

Monson Consultants
OK/AZ/CA – Civil Engineering & Hydrology

CalPoly University
San Luis Obispo, CA – CiVEN Adjunct Professor

AREA OF DISCUSSION

  - Pre-determined goal was stream habitat protection. Different than all other Groundwater Basin Studies in Oklahoma
  - Developed a simplified MODFLOW groundwater model to simulate recharge - storage - flow - discharge from eastern lobe of the aquifer
  - Used two (2) points of calibration of for the transient model. Blue River gage 07332390 & Pennington Creek (x = 27'3' - 39')
  - Manipulated recharge in model to produce stream discharges that mimic the two calibration points
  - Does not appear that the transient model was calibrated to the potentiometric surface for the same calibration period
STREAM FLOW ASSESSMENT

Base flow, the flow in a stream channel that represents groundwater discharge and not runoff from storms, was computed for Blue River near Converseville (07332390) and Pennington Creek near Ranger (07331300) by using the SCS method in WaterGAP. The SCS program scans the streamflow record from upstream for days that fit a requirement of antecedent precipitation designates base flow to be equal to the runoff. If it is not, and flow, it interpolates the daily record of base flow for days that do not fit the requirement of antecedent precipitation (Pitlick, 1998). Flow in Blue River near Converseville was computed as 65 percent base flow and flow in Pennington Creek near Ranger was computed as 70 percent base flow. The 5-year period from October 1, 2003, to September 30, 2008. Flow in Bydde Mill Spring is only groundwater, with no surface-water components, and therefore, is 100 percent base flow.

INVESTIGATORS BELIEVE – "BASEFLOW = RECHARGE"
RECHARGE ESTIMATES

The primary method used to determine recharge for the Arbuckle-Simpson aquifer for this study was a recession-curve displacement method, originally developed by Ronagh and Swank (1961). This method is based on the measurement of the change in the total potential groundwater recharge (base flow) estimated at a critical time after the peak of the recession period. The recharge from each precipitation event is assumed to be the difference between the groundwater discharge at the beginning of a recession period and the groundwater discharge at the end of the recession period. Recharge commonly is divided into recharge from infiltration and recharge from the surface water flow. Recharge from infiltration is difficult to quantify because the recharge rate can vary greatly over short spatial and temporal scales, and is difficult to measure directly. Recharge estimated at an average recharge rate to the Arbuckle-Simpson aquifer of about 4.7 inches per year.

Recharge for the data shown in Table 5 is greater than the average recharge calculated by Ronagh and Swank (1961). The difference is thought to be primarily caused by the difference in the recharge calculation method. The ratio of the recharge to the ground area is used in this study to calculate the annual recharge rate to the Arbuckle-Simpson aquifer. The recharge calculation method is used in this study to calculate the annual recharge rate to the Arbuckle-Simpson aquifer.

<table>
<thead>
<tr>
<th>Month</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (inches)</td>
<td>2.5</td>
<td>1.9</td>
<td>3.2</td>
<td>4.4</td>
<td>5.6</td>
<td>6.8</td>
<td>7.9</td>
<td>8.1</td>
<td>9.2</td>
<td>10.3</td>
<td>11.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Groundwater Discharge (MGD)</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 5: Rainfall recharge and groundwater discharge in inches and MGDs in the Arbuckle-Simpson aquifer in central Oklahoma.
RECHARGE SIMULATION

Recharge

Recharge was modeled using the MODFLOW recharge package, which simulates recharge from infiltration of precipitation through the soil zone. Recharge was only applied at the land surface, which is lower in the eastern Arbuckle-Temmered Hills area. Recharge was distributed in the eastern Arbuckle-Temmered Hills area model by zones based on the hydrogeologic unit at the land surface (fig. 3). Three recharge zones initially were assigned: Arbuckle-Temmered Hills, Simpson, and post-Simpson units, respectively. Hydrogeologic units were not assigned in the model, and recharge was by recharge. The Arbuckle-Temmered Hills recharge zone was subdivided during field testing at the South Fork Blue River site. The South Fork Blue River site: MODFLOW model is used to represent this site. Saline faults were used during the Model Calibration section of this report.

Daily recharge rates calculated by using the ROPE program and data from the South Fork Blue River site, and Pennington Creek near Reagan, Oklahoma. The recharge rates were used for calculating recharge in the MODFLOW model. The Recharge section in the Model Calibration section of this report. Model-calibrated daily recharge rates were adjusted from these data during the simulation calibration process (see the Model Calibration section of this report).

RECHARGE - STEADY STATE MODEL

Hills hydrogeologic unit. Recharge was initially estimated to be 4.7 inches per year, based on the average estimated by Faulenbach and others (1990), since the Arbuckle-Temmered Hills hydrogeologic unit was at the land surface, one order of magnitude less for the Simpson and two orders of magnitude less for the post-Simpson unit. The estimated recharge was initially estimated to be 1.0 in all hydrogeologic units.

Saline fault. Therefore, the recharge zone for the Arbuckle-Temmered Hills area was divided into two zones separated by the Saline fault. Recharge north of the Saline fault was set at 4.2 inches per year, and recharge south of the Saline fault was set at 1.6 inches per year (1.99 × 10⁻⁵ m d⁻¹). Recharge in the Arbuckle-Temmered Hills area was estimated by the authors of this report and observed and simulated flows in Blue River and Pennington Creek. After the improvement was noted in the model by assigning different recharge zones north and south of the Saline fault, a zone hydraulic conductivity in the Arbuckle-Temmered Hills area north and south of the Saline fault was taken, but no improvement was observed in the distribution of simulated heads and flows for a total area.
RECHARGE SIMULATION

RESULTS – STEADY STATE MODEL (Aug 14, 1995)
RESULTS – STEADY STATE MODEL (Aug 14, 1995)

A groundwater model simulates the budget, commonly referred to as a water budget, the redistribution of groundwater through the use of empirical models. The water budget for the eastern Arbuckle-Swea aquifer under steady-state conditions is 158.11 ft³/s of recharge and 158.11 ft³/s of discharge to drains. Simulated discharge for the steady-state model of 158.11 ft³/s is shown in Table 18; the difference, 1.43 ft³/s, is the difference between simulated streamflow and discharge for the entire model and actual groundwater flow systems with observed streamflow.

Table 18: Steady-state comparison of simulated and observed flow in ft³/s and ft³/s.

<table>
<thead>
<tr>
<th>Station</th>
<th>Flow (ft³/s)</th>
<th>Simulated (ft³/s)</th>
<th>Difference (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbuckle-Swea west</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Arbuckle-Swea east</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Smoky Butte</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Highwood</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Millers</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Jernigan</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Professional</td>
<td>158.11</td>
<td>158.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>632.44</td>
<td>632.44</td>
<td>0.00</td>
</tr>
</tbody>
</table>

RECHARGE – TRANSIENT MODEL

Recharge computed by the 80S2 system is based on streamflow gauge data and the rates of the subsurface storage units from the stream gauge. The recharge rate is averaged to 80S2 model recharge rates (Aug. 13) that are based on the hydrogeologic unit of the basin. Recharge is the recharge rate of the Arbuckle-Swea west, expressed as a percentage of the area. The recharge rate is determined to have an average of 1.299 meters of water (44 inches) per year. The annual recharge is estimated to be 1.299 meters of water (44 inches) per year. The area-weighted applied rate is taken from the state of Oklahoma, which is 0.773 ft³/s of water applied per acre. The area-weighted applied rate is the average of the area-weighted applied rates in the Arbuckle-Swea west, expressed as a percentage of the area.

Table 19: Area-weighted applied rate [cm/year] for western Oklahoma.

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
<td>0.77</td>
</tr>
</tbody>
</table>
STREAM CALIBRATION – TRANSIENT MODEL

Although the transient model calibration was primarily based on streamflow at Blue River and Pennington Creek, the model also reproduces head response in observation wells. Comparison between observed and simulated heads in observation wells is shown in Figure 38. Daily head observations were compared to simulated heads, and good agreement was observed. The simulated heads reproduced the general character of the observed heads, although there were some differences, particularly at the eastern end of the study area.

Figure 38: Comparison of simulated and observed heads in observation wells. The solid line represents the observed head, while the dashed line represents the simulated head.

WELL CALIBRATION – TRANSIENT MODEL

Figure 39: Comparison of simulated and observed heads in observation wells. The solid line represents the observed head, while the dashed line represents the simulated head.
**WELL CALIBRATION – TRANSIENT MODEL**

![Graphs showing well calibration and transient model results.](image)

*Figure 26: Comparison of observed and simulated BTCs for various time periods. The model results are shown with different symbols and colors. The figure highlights the transient behavior of the well. (Continued)*

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**PRIOR RIGHTS**
- 11 Permits
- 5696 Ac-Ft

**Temporary Permits**
- 48 Permits
- 74,524 Ac-Ft
- 45,419.9 Ac

**Pending Permits**
- 13 Permits
- 129,814.6 Ac-Ft
- 57,128.4 Ac
AREA OF DISCUSSION

- **Phased Implementation of Maximum Annual Yield**
  - Under recommendations, Maximum Annual Yield = 78,404 Ac-Ft
  - Existing Allocations (Prior and Temporary Rights) = 80,220.3 Ac-Ft
  - Current "Over Allocation" = 1816.3 Ac-Ft
  - If all existing temporary permits are immediately converted to 0.2 Ac-Ft / Acre then (45,419.8 Ac X 0.2) = 9083.98 Ac-Ft
    - Available Additional Allocation = 9083.98 Ac-Ft
  - If all existing pending permit applications are awarded at 0.2 Ac-Ft / Acre then (57126.4 X 0.2) = 11,425.68 Ac- Ft
    - Available Additional Allocation = 52,199.34 Ac-Ft